

Guidance on Monitoring Upwind of Urban
Areas for Determining Transport of
Ozone and Its Precursors

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GUIDANCE ON MONITORING UPWIND OF URBAN AREAS
FOR DETERMINING TRANSPORT OF OZONE AND ITS PRECURSORS

Monitoring and Data Analysis Division
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PURPOSE

The purpose of this report is to provide specific guidance for collection of ozone and precursor data, where needed, to define upwind transport into cities. Certain requirements or recommendations for upwind monitoring have been made in connection with the Level III modeling analysis recommended as the minimum modeling requirement in the development of 1982 ozone SIPs. In addition, some States and localities may wish to perform more sophisticated modeling. This supplementary, specific guidance for upwind monitoring is needed because:

- 1) upwind monitoring has not previously been required, nor has it been routinely performed in more than a few areas of the Nation;
- 2) upwind monitoring is needed, not to determine compliance with air quality standards but for control strategy planning activities associated with achievement of the ozone standard;
- 3) the nature and extent of upwind monitoring varies, depending on which of several O_3 -precursor relationships (models) are used for control strategy planning;
- 4) where upwind monitoring is needed, several practical approaches (varying in cost and complexity) are available depending on how definitive a measure of transport is needed or desired; and,
- 5) upwind monitoring presents some unique problems not generally necessary to consider for other monitoring needs.

This report attempts to describe the above circumstances more completely and provides guidance in effectively carrying out an upwind monitoring program.

The guidance is based primarily on the results of a special field study conducted in the Philadelphia area during the summer of 1978 for the purpose of evaluating approaches for measuring ozone and its precursors upwind of an urban area. Five approaches from among those considered possible were field tested, and the findings form a principal basis for the recommendations made in this report. The following sections describe the 1978 field study and its principal findings. The study was performed under contract to EPA by AeroVironment, Inc. and is fully described in EPA-450/4-79-039.¹

Measurement Approaches Evaluated

Fixed Surface Monitoring Upwind

Various parameters were monitored continuously at five surface monitoring stations in directions generally upwind of Philadelphia during the summer oxidant season. These parameters were: O_3 , $NO/NO_2/NO_x$, THC/CH_4 , wind speed, wind direction, temperature, solar radiation, and mixing height. Ozone and oxides of nitrogen were measured using EPA reference methods. There are currently no reference methods for measuring non-methane hydrocarbons, but methods recommended by the Environmental Monitoring Systems Laboratory (EMSL) at RTP were used. Meteorological parameters were monitored using generally accepted methods. Also, hydrocarbon samples for species analysis were taken at some of the stations. Locations of these monitoring stations are shown in Figure 1.

Dedicated Instrumented Aircraft

A Bell UH/1H helicopter was used. Measurements were performed by the EPA-Las Vegas Environmental Monitoring Systems Laboratory. Parameters measured included O_3 , NO , NO_x , visible light scattering, temperature, and dew point versus altitude, location and time. Ozone and oxides of nitrogen were measured using instruments which meet EPA reference method specifications. Their use in the aircraft, however, did not meet these specifications, because a faster response setting was used, and also the temperature on the aircraft did not meet the specifications. Hydrocarbon grab samples were taken on some flights at two elevations for subsequent species analysis.

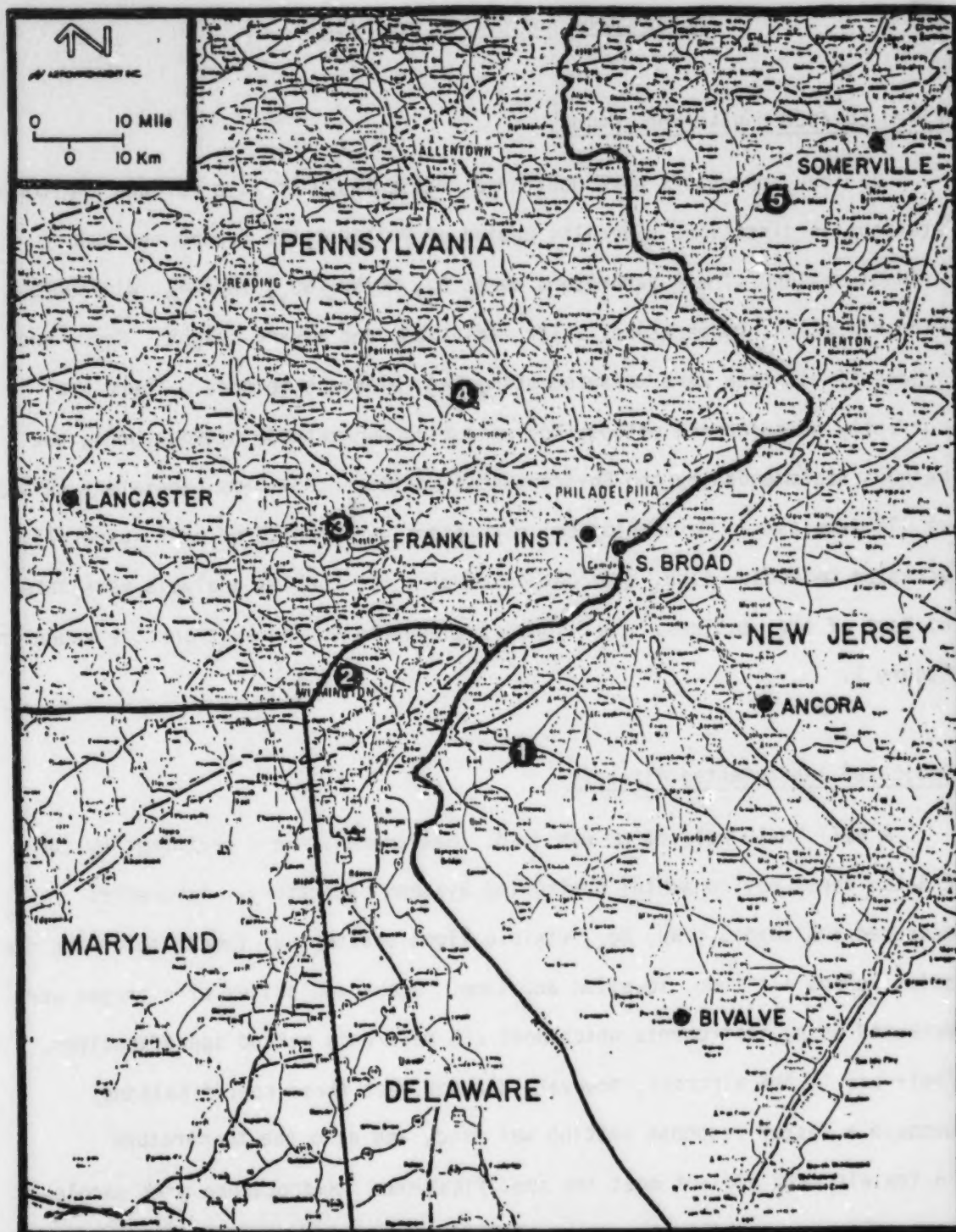


Figure 1 - Locations of Monitoring Sites. Numbered Sites are Transport Measurement Stations and Dots Represent Supplemental Stations.

Portable Instrument Package

The package contained portable, battery-operated ozone and temperature sensors which could be placed in a light aircraft with no aircraft recertification requirement. For this project, a Cessna 171 was used. The ozone instrument was a Columbia Instruments Model 2000 chemiluminescent O_3 analyzer. The operating gas was a nonflammable ethylene mixture (Ethychem) in a low-pressure container, which was exempt from the hazardous materials transportation regulations. The analyzer has a range of 0 to 0.5 ppm and an accuracy of ± 0.005 ppm when operated with pure ethylene; the performance is degraded slightly when Ethychem is used. This analyzer meets EPA reference method designation specifications when ethylene is used, but does not meet these specifications when Ethychem is used.

Free Balloon Ozonesonde System

The system consisted of a Mast 730-9 ozonesonde and an Atmospheric Instrumentation Research Company AS-1C three-channel airsonde. The radio transmitter on the airsonde transmits temperature, pressure, and ozone data to an Atmospheric Instruments Company TS-2A ground station. The combined ozonesonde/airsonde instrument package was flown under a 350-gram free lift balloon with a rate of rise of approximately 100 m/min. The ozonesonde, in its original form, measures total oxidants and, thus, responds also to SO_2 and NO_2 in ambient air. During the tests, an absorber column packed with glass fiber paper, impregnated with CrO_3 and H_2SO_4 (Mast Model 725-30 SO_2 filter kit), was added to the intake of the ozonesonde. The column removes SO_2 and allows the detection of ozone concentrations without interference from other

oxidants. Tests indicated that the removal of SO_2 is 100% complete if the column is used for no longer than 540 ppm-hr. of sampling. The absorber also completely converts NO to NO_2 , which gives a positive interference of about 10% of the NO_2 concentration to the O_3 measurements. The ozonesonde has a range of 0 to 0.5 ppm and an accuracy of ± 0.01 ppm. Currently, the ozonesonde does not meet EPA equivalency requirements.

Tethered Balloon Ozonesonde System

This system consisted of a Mast 730-9 ozonesonde and an Atmospheric Instrumentation Research Company TS-2A tethersonde supported by a 4.25m³ kytoon (Model TS-1BR-2) with a TS-2A ground station. An absorber column packed with glass fiber paper, impregnated with CrO_3 and H_2SO_4 , was also added to the intake of the ozonesonde for removing SO_2 and NO_2 . The range and accuracy of this system in measuring ozone are identical to those of the ozonesonde used with the free lift balloon.

Other Possible Approaches

Other measurement approaches not field tested are possible but believed too impractical, costly, or in some incomplete stage of research. Among these are measurements by moving vehicle, on towers or tall buildings, manned balloons, remote sensing techniques, etc. These are discussed further in EPA-450/4-79-039.

Note: Although some of the above methods do not meet EPA reference or equivalency requirements, they can still provide useful data for estimating upwind levels of transported pollutants. For this purpose, some flexibility in the use of such data is admissible, provided acceptable quality assurance procedures are followed. This pertains mainly to airborne measurements which often provide a better indication of transported pollutant levels than do surface measurements, but are considerably more difficult to obtain using methods meeting all the EPA requirements at a reasonable cost to most agencies.

Field Performance of Measurement Approaches

Data collected during the summer of 1978 in Philadelphia indicates that:

- (1) there is no obvious transport of significant concentrations of ozone and precursors along the surface into Philadelphia during the early morning hours;
- (2) transfer of significant precursor concentrations aloft is generally not apparent;* (3) transport of ozone aloft, in excess of 0.08 ppm, is at times observed; and (4) there is no significant difference in ozone concentrations along the upwind boundary of Philadelphia in the air mass aloft. These findings suggest that the measurement techniques should be evaluated primarily for whether or not they can quantify the ozone transport aloft. The following discusses the performance of each of the five techniques that were evaluated.

Fixed Surface Monitoring Upwind

Ozone trapped aloft overnight is mixed downward to the surface after the breakup of the surface-based inversion. If the time when ozone transported aloft were mixed to the surface were known, it could be determined from surface readings when surface concentrations would most nearly reflect ozone concentrations transported aloft.

During the Philadelphia study, an acoustic radar was installed at a fixed-surface monitoring station upwind. Records from radar indicate when the surface inversion begins to be eroded and when mixing in the vertical is no longer inhibited by any remnants of this inversion. The record taken on the morning of August 23, 1978 (shown in Figure 2), shows a typical example of stable atmospheric structure extending from the surface to 220m between 0700 to 1000 EDT. From then until 1100 EDT, the surface-mixed layer deepens, after which mixing in the vertical is virtually uninhibited.

* Except in isolated cases where apparent elevated point source plumes are encountered.



Figure 2. Acoustic Radar Record at Site 1 on August 23, 1978

A comparison of the average surface ozone reading for the hour following the onset of unlimited mixing, which was determined from the acoustic radar records and the helicopter measurements of ozone concentrations aloft, indicated that the average difference between the surface and aloft readings on eight occasions, including August 23, 1978, was 0.005 ppm. This suggests that, if the time of the completion of vertical mixing is known, surface measurements of ozone can be used to closely approximate the level of ozone transported aloft. A major advantage of surface measurements is that it is the only method which allows continuous measurements, and thus assurance, that measurements exist for days or at times of day which are later determined to be of interest for control strategy development or other use.

Airborne Measurements by Dedicated Instrumented Aircraft

The capability of a dedicated instrumented aircraft to measure the ozone transported aloft is obvious. The soundings taken by the dedicated instrumented helicopter during the study provided valuable information on the vertical ozone profiles. From surface measurements, one can only infer the ozone levels aloft. As discussed earlier, in most cases it is probably not necessary to measure precursor levels aloft. Little difference was observed between precursor levels aloft and below transported into the urban area. Transported precursor levels (i.e., NMOC and NO_x) were generally low; hence, precursor levels measured at the surface should usually suffice. Thus, the combination of a dedicated instrumented aircraft measuring ozone and lapse rate, and an upwind surface monitoring station measuring ozone precursors and wind, would provide directly all the needed information on the transport of ozone and precursors into an urban area.

Portable Instrument Package

A portable instrument package mounted in an aircraft is another direct means of measuring the concentration of ozone aloft. The reliability of this approach was tested by comparing it with that collected by the dedicated instrumented system in the U.S. EPA helicopter. Eight side-by-side flights were made with the portable instrument package and the helicopter in Philadelphia. Figure 3 shows a comparison of vertical profiles for one set of flights. The helicopter profile data are closely reflected by the profile from the portable instrument package. The readings from the portable instrument package, however, are about twice those measured by the helicopter. The plots shown are reflective of the other seven comparisons. The readings from the portable instrument package were always higher, but not at a consistent ratio from sounding to sounding. The discrepancy was apparently caused by a zero shift of the ozone instrument of the portable package tested. This may have been a characteristic problem for this package or type of package; this has not been resolved.

The recording signal from the ozone instrument used in this study was also rather noisy, a consequence of the high amplifier gain settings required when Ethychem was used instead of pure ethylene in the reaction cell. Thus, the profile is not as smooth as that from the helicopter or the ozonesonde. If bottled ethylene were to be used, the signal-to-noise ratio would improve three-fold. However, the use of ethylene gas in an aircraft would require recertification of the plane in the "restricted" category, which defeats one of the desirable features of a portable instrument package. As noted earlier, the instrument used here does not satisfy EPA reference method designation specifications when operated with Ethychem gas.

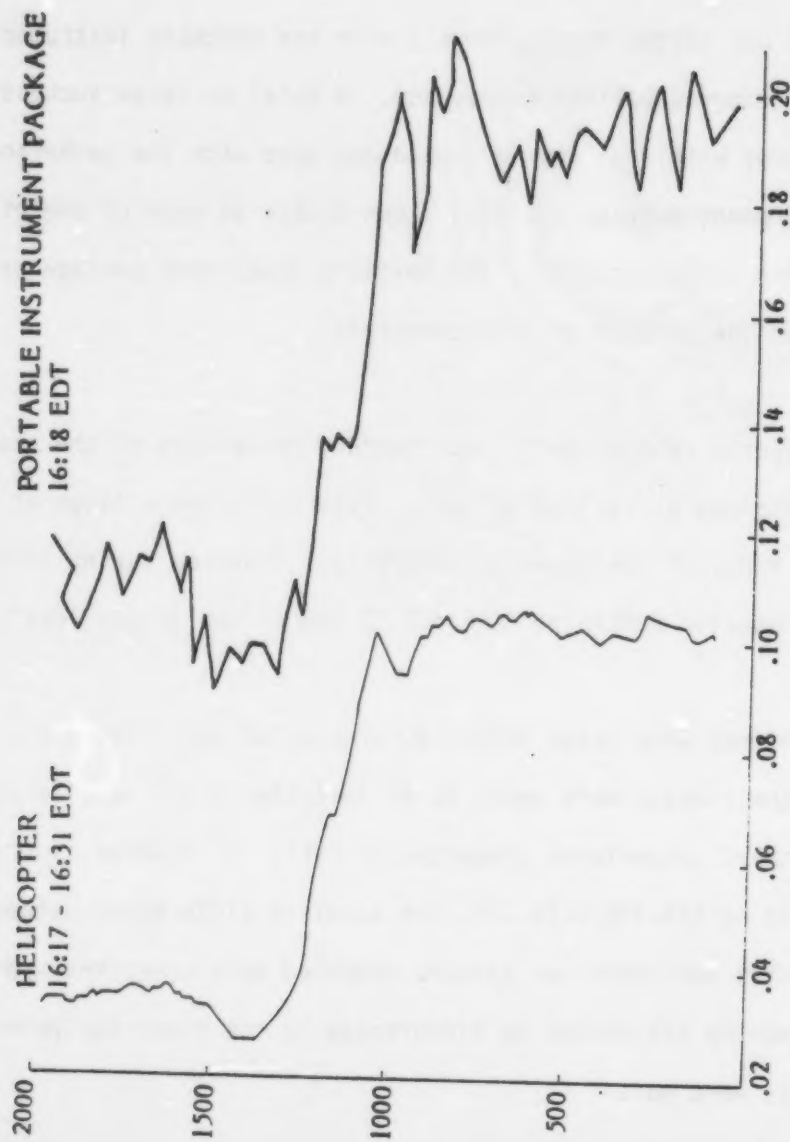


Figure 3. Vertical profiles of ozone obtained by the portable instrument ozone package and the instrumented helicopter on the afternoon of August 24, 1978, over Site 1.

Based on data gathered to date, it is uncertain whether this portable instrument package can be used to measure ozone aloft, as simply and accurately as was originally hoped. Further testing of the package is necessary.

Free Balloon Ozonesonde System

This system was tested simultaneously with the portable instrument package and the tethered balloon ozonesonde. A total of seven successful soundings were made within an hour of soundings made with the tether sonde; the portable instrument package was also flown within an hour of one of those soundings. On two other occasions, the portable instrument package was flown within an hour of the release of the ozonesonde.

Table 1 presents ranges, means and standard deviations of the ozone concentration obtained by various methods. Data points were taken at 100 m intervals. The range of the ozone concentrations observed during each sounding is limited, usually remaining within 0.02 ppm of the ground-level value.

If the soundings were taken within 30 minutes of each other, the absolute differences of their means were equal to or less than 0.010 ppm, as shown by the second and third comparisons presented in Table 1. However, for various reasons explained in EPA-450/4-79-039, the absolute differences between the free balloon system and other two systems compared were sometimes appreciable, but these were mostly attributed to differences in the times the paired profile measurements were made.

Ozone concentrations observed by the ozonesonde before release were always within ± 0.01 ppm of the surface station reading, indicating that

Table 1. Comparison of Ozone Data (ppm) Provided by Ozonesonde Beneath a Free Balloon and Portable Instrument Package

	Date	Approx. Time (EDT)	Range		Means		Standard Deviation		Absolute Difference of Means	Number of Pairs of Data
			Portable Package	Ozonesonde	Portable Package	Ozonesonde	Portable Package	Ozonesonde		
Ozonesonde versus Portable Package	9/27	1500	.037-.073	.063-.088	.057	.081	.008	.009	.024	18
	9/27	1900	.044-.087	.046-.073	.057	.067	.010	.007	.010	19
	9/30	0700	.046-.068	.032-.057	.057	.048	.006	.006	.009	19
Ozonesonde versus Tethered Sonde	9/27	1200	.078-.083	.050-.060	.082	.054	.002	.004	.028	6
	9/27	1500	.061-.068	.085-.088	.066	.086	.002	.001	.020	6

ozonesonde readings are accurate to within the specifications of the instrument. The free balloon ozonesonde is thus a good candidate for measuring ozone aloft, provided appropriate corrections are made for reduced pressure aloft.

Tethered Balloon Ozonesonde System

Ozone soundings obtained with this system were compared against those obtained with the dedicated instrumented helicopter, the free balloon ozonesonde system, and the portable instrument package. Results show that the tethered ozonesonde accurately measures ozone concentrations aloft when the instrument is carefully calibrated. The major drawback (in its present configuration) is its limited vertical range, at least with the balloon used in the study. During the tests, soundings were seldom made beyond 500 m; the design altitude for the balloon was 1,000 m. As indicated by data from the other airborne techniques, the ozone structure above 1,000 m is often significantly different from that in the lower 1,000 m. A larger balloon would provide a greater altitude capability, at the expense of ease in ground handling of the balloon.

SUMMARY OF TECHNIQUES EVALUATED AND COMPARATIVE FACTORS

Of the five measurement techniques evaluated, surface measurements at fixed sites, airborne measurements by dedicated instrumented aircraft, and soundings by ozonesonde beneath a free balloon are all practical means of measuring directly or providing information on ozone concentrations transported aloft. If precursor measurements are needed or desired, they may be added to surface stations and/or dedicated aircraft.

In selecting the technique to use, one should consider factors such as technical capability and available funding, and the intended use of the data. Table 2 ranks the three acceptable approaches in terms of cost, technical expertise required to operate, and the uses of the data generated, and serves as a simple guide to help the agencies make a selection. In most cases, surface ozone measurements with a means of determining time of inversion dissipation, will provide a reasonably accurate, lower cost estimation of significant photochemical pollutant (i.e., ozone) transport.

It is uncertain, based on the data collected thus far, whether the portable instrument package would serve the purpose of measuring the transport of ozone aloft. It would be worthwhile to perform further tests on the system to be sure of its applicability.

The tethered balloon ozonesonde system tested here could not obtain information beyond 1,000 m above ground level. Since significant ozone structures often exist above that elevation, its applicability is somewhat limited.

Table 2. Comparison of Proven Approaches for Measuring or Obtaining Information on Ozone Concentrations Aloft

Method	Approximate Costs			Technical Expertise Required	Intended Use of Data		
	Initial Cost	Labor ^a	Operation Others		Routine Surveillance	Input to Models	Vertical Profiles
1. Surface Measurements, ^{b,c} Fixed Sites, per site	\$15-25,000 ^d	\$1600/mo.	\$500/mo.	Moderate	x	x	
2. Airborne Measurements, ^b Dedicated Aircraft	\$70,000	\$ 160./ sounding	\$250/ sounding	High		x	x
3. Soundings, Ozone sonde Underneath Balloon	\$ 5,000	\$ 30/ sounding	\$250/ sounding	Low		x	x

^a Labor rate assumed to be \$8/hour

^b For comparability of all three systems, only ozone measurements assumed. Costs would increase for precursor measurements, but less than proportionately.

^c An acoustic sounder for use with 03 surface monitors rents for about \$850/month, assuming operation by user.

^d Depending on availability of site, shelter, and whether in-house or by contract.

Note: Instruments and expendables included in above costs.

RECOMMENDATIONS

Ozone

Agencies required to monitor ozone upwind should generally use at least one surface station. More stations may be needed if particular urban plume transport may be expected. Generally, impact of particular urban plumes could not be distinguished by the network of five upwind monitors in Philadelphia. The nearest large urban area upwind of Philadelphia (Baltimore) is about 40 air miles distant. Hence, perhaps urban areas at closer separation distances, or for urban areas larger than Baltimore at comparable or somewhat greater distances upwind, may require more than one upwind site.

Ozone measurements averaged during the first hour after inversion lifting (as might be determined by an acoustic sounder) should be used. Otherwise, an average surface ozone concentration for 1100-1300 LDT would be appropriate.

For more accurate measurements of ozone transported above the surface layer in the early morning, as might be needed for Level I (photochemical modeling) analysis, aircraft or alternatively free lift ozonesonde measurements are preferred.

Precursors

The Philadelphia Study suggests that precursor measurements to estimate the impact of cities greater than about 40-50 miles distant on ambient precursor levels appear to be unnecessary for application of Level III analysis in SIPs. Precursors (hydrocarbons and nitrogen oxides) tend to decay at a greater rate than ozone downwind of cities. This is supported by data examined by OAQPS

from the St. Louis RAPS program. At closer interurban distances, some pilot surveys (perhaps using mobile stations to measure NO_x and nonmethane hydrocarbons by sum-of-species discrete sampling methods) might best indicate whether more routine precursor measurements are needed. If a city chooses to measure upwind NMOC, guidance contained in EPA-450/4-80-011² and EPA-450/4-80-008³ should be followed.

ADDITIONAL GUIDANCE

Additional guidance on surface monitor siting is contained in EPA-450/3-78-013⁴ and the May 10, 1979 Federal Register.⁵ In general, for upwind monitoring, the most frequent wind(s) associated with important photochemical activity should be determined. The prospective monitoring area for a single monitor should be upwind for the most frequent wind direction and outside the area of city influence for this wind direction. For more than one monitor, the areas upwind of the next more frequent direction(s) would be suitable to monitor or, if only one direction is prominent, monitors should be located radially about the most frequent upwind direction. For mobile or airborne monitoring, the upwind area for a particular day or situation can be determined based on actual and forecast wind conditions.

REFERENCES

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